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OCULAR HAZARD OF THE GAAS LASER

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INTRODUCTION

Semiconductor junctions, widely known as the basic element of solid state electronic devices, are also capable of generating visible and infrared photons, which under proper conditions are emitted in the coherent, monochromatic mode characteristic of laser radiation. This semiconductor laser has all the inherent advantages of solid state devices, including small size, low cost, high reliability, and ease of operation. The laser is operated by simply passing an electric current through the p-n junction, which yields an optical replica of the current waveform. The GaAs laser, the most efficient semiconductor laser, emits its radiation at wavelengths in the 8000 to 9000 Angstrom range, matching the peak sensitivity of silicon photodetectors and making possible all solid state systems.

Compared to other laser types, the GaAs laser is at a disadvantage in terms of peak power, collimation, and coherency. For some military applications these deficiencies are balanced by the above advantages, and the GaAs laser is used in intrusion alarm systems, secure communications links, and short distance range-finders. By use of multiple diode arrays, high average power visually covert illumination is possible for night vision and range gated systems.

Each of these applications exposes human eyes to GaAs laser radiation, and thus it is necessary to determine the ocular hazard of these lasers. To this end we have performed an experimental determination of the damage threshold of ocular damage to the GaAs laser.

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Materials and Methods

An RCA 7610 GaAs laser diode served as the radiation source in all the experiments. The laser was operated in the high repetition rate mode with the operating variables optimized for maximum average power. With the laser maintained at ambient temperature, junction heating caused by the high driving current restricted the duty cycle to 0.1% and the average power to 5 milliwatts, a level insufficient to produce ocular damage. Reduction of the diode temperature to cryogenic temperature enabled the diode to lase with much lower driving current. A much higher duty cycle was possible before junction heating became significant, resulting in greatly increased average power. A power supply was designed and constructed to drive the diode to maximum output and threshold experiments were performed with the cryogenically cooled laser.

The exposure system is depicted in Figure 1. The laser diode was mounted in a solid copper block comprising the cold finger of a LN₂ cryostat. A simple, 21.8 mm-focal-length lens collimated the laser emission and directed the resulting beam to a beam splitter which diverted 90% of the radiation into the eye, while a photomultiplier detected the transmitted 10%. A HeNe laser beam, introduced collinearly with the GaAs laser beam facilitated aiming and alignment. A goniometer mount for the experimental animal provided accurate rotation about the pupil of the eye to be exposed, allowing precise positioning of the exposures. The exposure sites were observed and photographed through the beam splitter, via a Zeiss fundus camera. An electronic camera shutter controlled the exposure duration.

Calibration of the exposure system was performed by placing the calibration standard--a TRG 100 ballistic thermopile, in the eye exposure position. Upon exposure, this detector measured the energy which would enter the eye (TIE), which was then expressed as a function of the output signal of the photomultiplier in the reference beam. A calibration was performed each day that an animal was exposed, minimizing the need for long term stability.

The beam characteristics were investigated as a necessary part of describing the exposure system. The optics of the delivery system were chosen to deliver the maximum irradiance at the retina. The uncollimated laser output lay almost entirely within a 28° cone. Best collimation, achieved in practice by obtaining the sharpest image of the p-n junction at a distance of 7 meters, produced a 5 mm beam at the eye position.

Given the collimator focal length of 21.8 mm and laser source dimensions of 230 x 2 μ, the expected beam divergence is 10.5 mrad x .1 mrad. A far field camera verified this expectation. The camera was positioned with the entrance aperture (coincident

with the lens) at the position in the system normally occupied by the experimental eye.

The far field pattern was photographed and the profile in both directions determined via densitometry. The profiles are consistent with the calculated beam divergence. At threshold the entire exit aperture emits uniformly, and the far field pattern conforms to a beam divergence of $11 \text{ mr} \times .2 \text{ mr}$. At operating levels above threshold, the laser ceases to emit uniformly along the length of the junction as exhibited by a nonuniform far field pattern. During the course of the experiments the camera was apertured down to considerably smaller than the pupil of the experimental animal eyes with no degradation of image other than reduced intensity.

The spatial distribution at the focal plane of the far field camera is that which should appear at the retina of an unaccommodated emetropic eye, assuming equal optical quality, with a reduction in size proportional to the focal lengths. Thus the expected retinal energy distribution is completely described.

Ancillary to the preceding was an investigation of the wavelength emitted by the laser. The output wavelength of the semiconductor laser is temperature dependent, shifting approximately 2.5 \AA per $^{\circ}\text{K}$. When the laser is first turned on there is a rapid shift toward longer wavelengths as the temperature rises to accommodate the heat created by the driving current. The wavelength stabilizes when the diode reaches a temperature at which the heat is dissipated at the generating rate. All the exposures in these experiments included that shifting portion of laser output. Therefore, the shift was experimentally evaluated. The wavelength shifted rapidly from the initial value of 8525 \AA , stabilizing in 0.4 seconds at 8640 \AA with a bandwidth of 26 \AA .

Procedure

The animals used in these experiments were Rhesus Monkeys (*Macaca Mulatta*) weighing between 2 and 5 kg. Preanesthetic medication consisted of a sedative dose of phencyclidine hydrochloride (0.25 mg/kg) intramuscular and atropine sulfate (0.2 mg) subcutaneously. Anesthesia was induced with sodium pentobarbital (approximately 5 mg/kg) via the saphenous vein. A pediatric intravenous injection set was placed into the saphenous vein to administer fluids and to facilitate additional anesthetic. The pupils were dilated with phenylephrine hydrochloride (10%) combined with cyclopentolate hydrochloride (1%). Sutures of 3-0 silk were placed in the upper eyelid to facilitate manipulation. While the eyes were open during the experiment, physiologic saline was used to maintain good corneal transparency.

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The animals were positioned in the exposure system and the fundus examined via the Zeiss fundus camera. Any abnormalities were noted. Twenty-five to thirty-six exposures were placed in a square array about the macula, utilizing suprathreshold marker burns to accurately locate the rows and columns for subsequent visual and histopathologic examination.

An absorbing filter (OD 18 at $.9 \mu$) placed over the eyepiece of the fundus camera allowed direct observation of the exposure site during the longer exposures. Eye movement during the exposures was thus detected, and any exposure so compromised was excluded from further consideration.

Detailed ophthalmoscopic examination of the exposure sites was conducted at one hour post exposure. The criteria for damage was the presence of a lesion visible via this examination, in all except the 1 second exposure experiment. In that experiment, the criteria for damage was the presence of a lesion visible via fundus camera at 24 hours post exposure.

The retinal lesions appeared as circumscribed whitish retinal opacifications that ranged in size from approximately 100μ to 1000μ (size was exposure power dependent). In no case was sufficient energy delivered to result in hemorrhage.

Results

Threshold data was obtained at exposure durations of 0.125 sec, 0.5 sec, 1 sec, and 8 sec. The exposure parameters listed in Table I were maintained during these experiments. Pulse width and repetition rate were held constant.

TABLE I

(Beam Parameters Measured at Eye. (77°K))

Peak Power	-	1.4 watts max.
Pulse Width	-	500 nsec
Pulse Shape	-	~ Square
PRR	-	120 KHz
Average Power	-	100 milliwatts max.
λ	-	8525 \AA to 8640 \AA

The data was subjected to exact probit analysis, the results of which are given in Table II and Figures II and III.

TABLE II

Exposure Duration	<u>.125 sec</u>	<u>.5 sec</u>	<u>1.0 sec</u>	<u>8.0 sec</u>
No. of Animals	4	5	7	5
No. of Eyes	5	7	13	7
No. of Exposures	130	198	448	285
ED ₅₀ (Energy)	7.0 mj	19.0	39.0	155.4
(Power)	55.6 mw	37.9	39.0	19.4
ED _{0.1} (Energy)	4.0 mj	5.1	17.5	55.9
(Power)	32 mw	10.2	17.5	7.0
Lowest Burn (Energy)	6.6 mj	13.4	28.6	131
(Power)	52.8 mw	26.8	28.6	16.4

The ED₅₀ level is plotted as a function of exposure duration in Figure IV, indicating the ED₅₀ level to be inversely proportional to the 4th root of the exposure duration, consistent with results from other lasers.

Discussion

There remains one enigma which renders the results of these investigations less than totally predictable. The laser beam characteristics were such that a well behaved positive lens system would produce an elongated rectangular image at the focal plane. The unaccommodated emetropic eye is considered such a system, and the retinal irradiation configuration should be a rectangle of dimensions 170 μ by 20 μ (diffraction limited). However, the retinal burns were in all cases nearly circular in shape and greater than 100 μ in diameter. Because diffraction limited beams produce smaller than 100 μ burns, it would be expected that the damage area would be smaller in one dimension yielding an elongated lesion. No satisfactory explanation for this discrepancy has been found, and until it has been resolved the retinal irradiance area remains uncertain, making extrapolation of these results to other exposure configurations uncertain.

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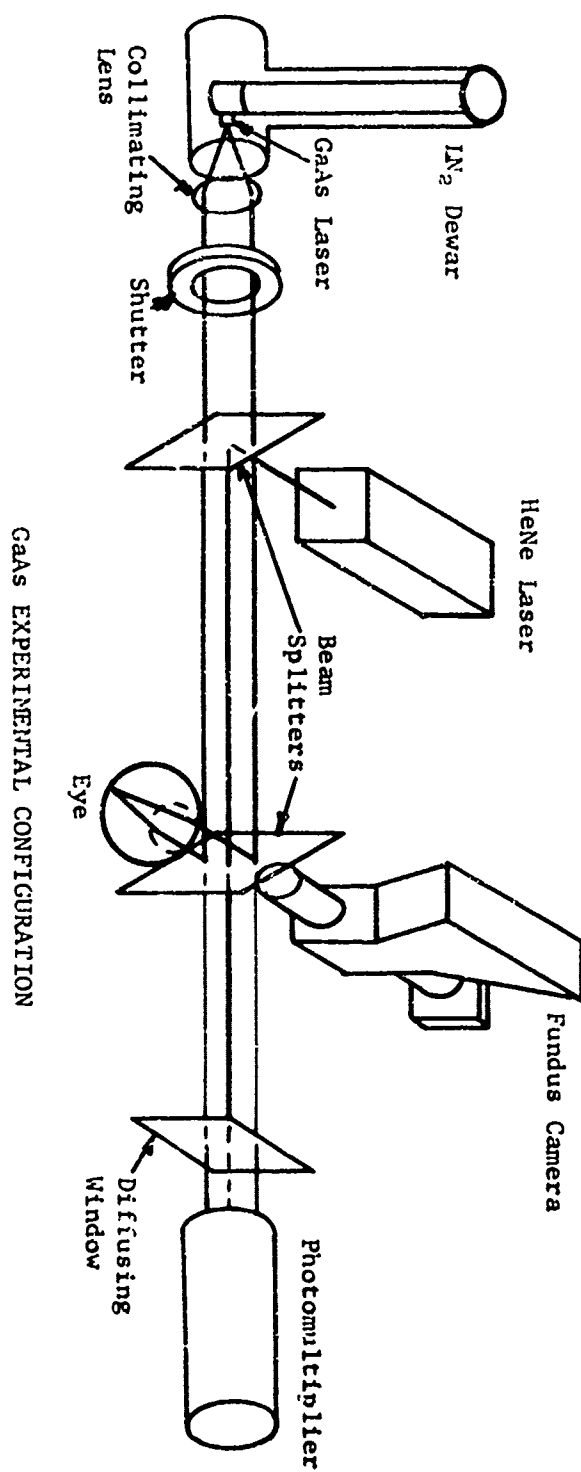


Figure 1

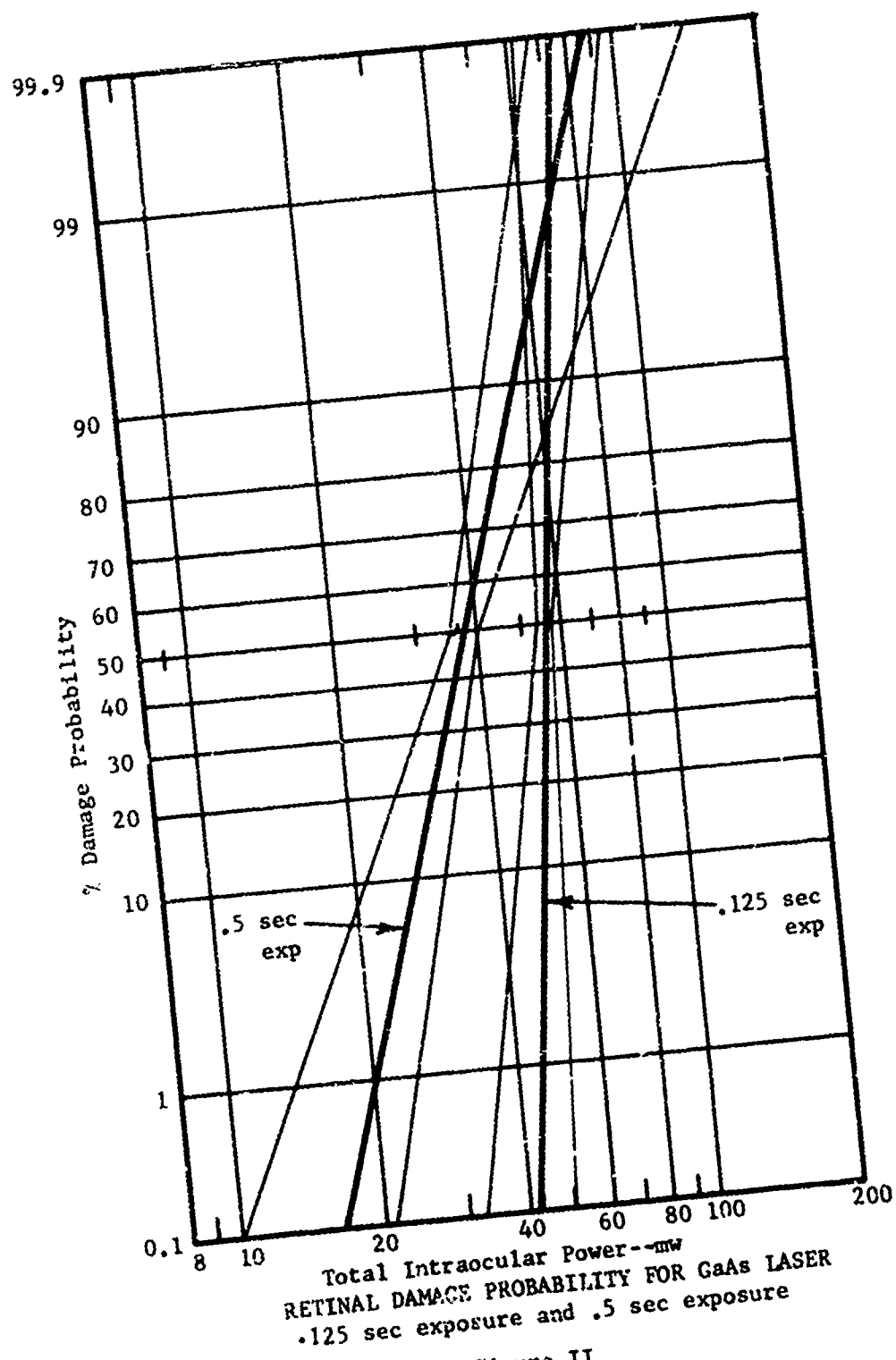
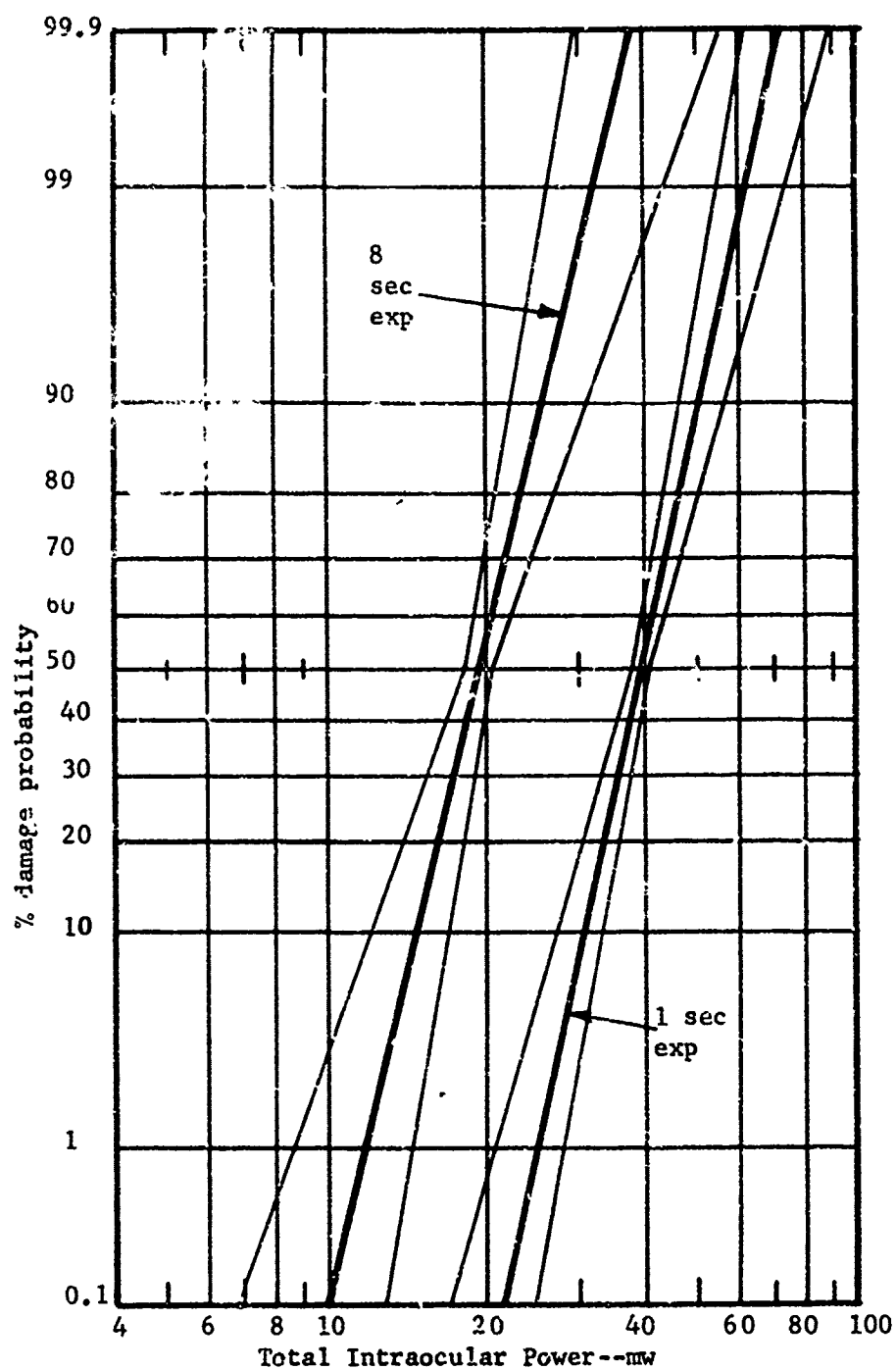


Figure II

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RETINAL DAMAGE PROBABILITY FOR GaAs LASER
8 sec exposure and 1 sec exposure

Figure III

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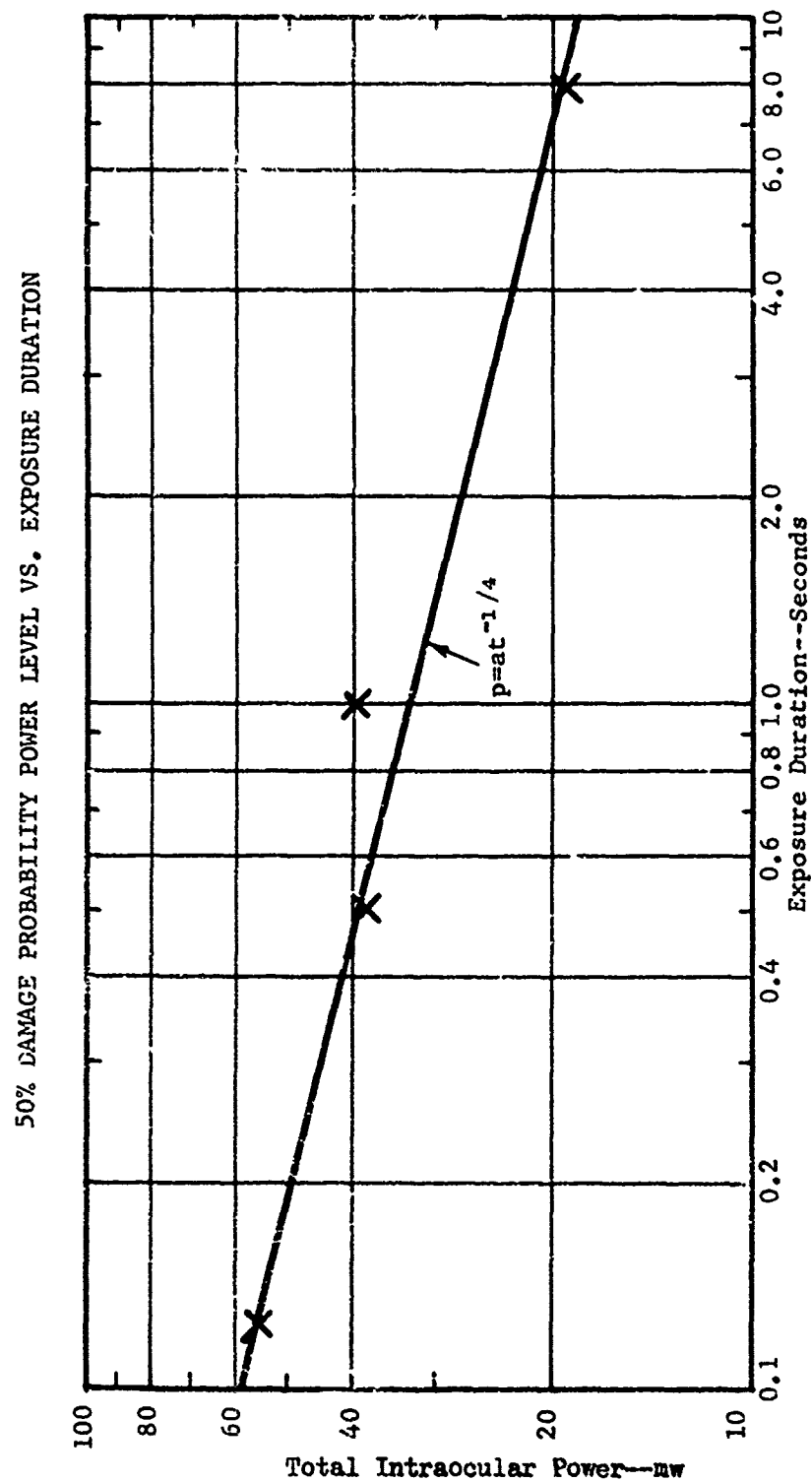


Figure IV

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